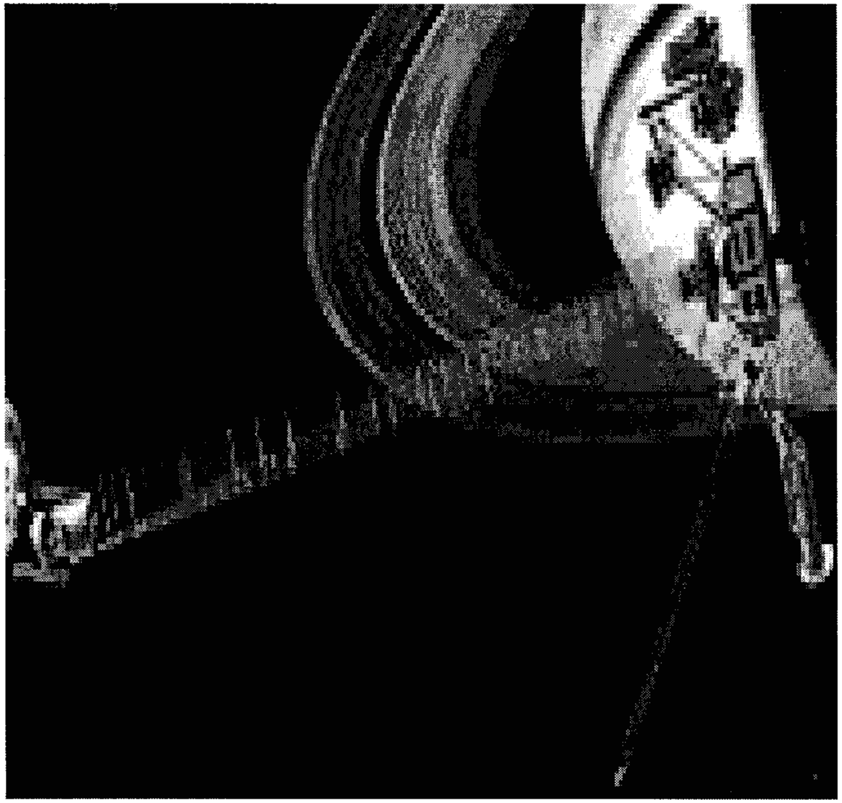
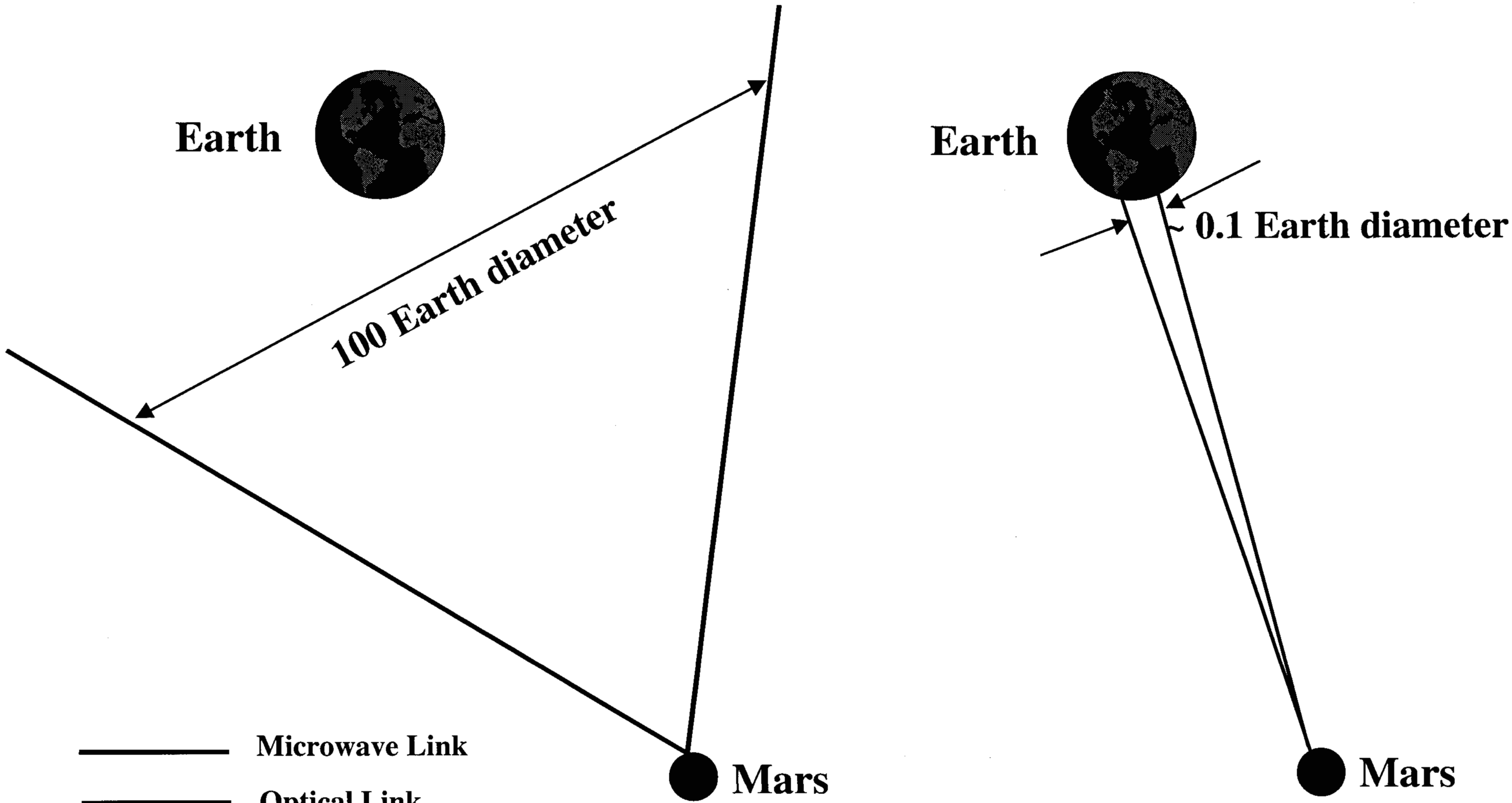


Free-Space Optical Communications at NASA

H. Hemmati & K. Wilson

Optical Communications Group
Communications Systems and Research Sec.
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

Beam Divergence (Frequency) Effect



Potential of Laser-Communication Technology

- Assuming identical antenna/telescope aperture size for both the space and the ground terminals, the frequency dependence provides nearly 90 dB (10^9) advantage for optical over X-band frequency

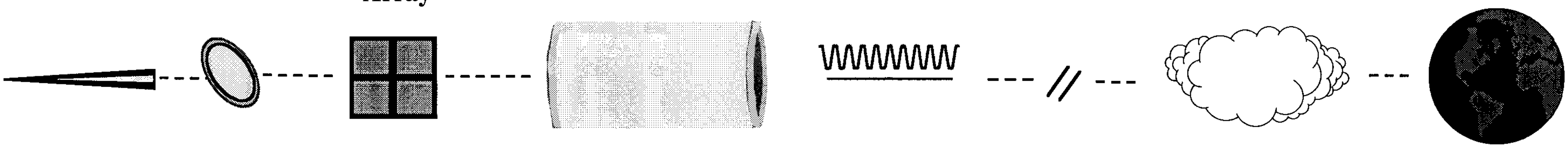
- Aperture of a typical lasercomm flight terminal is ~ 1/10 that of RF systems assumed ground receiver telescope apertures are about 10-m in diameter compared with 70-m DSN antennas

- Current optical receivers are significantly inferior to RF receivers
- Current laser transmitters are > 70% less efficient than RF transmitters
- > 4dB is lost in propagation through the atmosphere

⇨ 8-11 dB remains which can be used, for example, to provide > 10X higher data-rate (for same input DC power)

⇨ Significant (> 10 dB) component efficiency improvements can be realized (through technology development) on top of the current advantage

Free-Space Optical Communications
Design Drivers



Laser
- Efficiency
- Power vs. data rate
- Extinction ratio
- Reliability

Fine-Pointing Mirror
- Bandwidth
- Reaction
- Performance
- Reliability

Focal Plane Array
- Type
- Array size
- Pixel size
- Noise
- Spectral band
- Field-of-view
- Dynamic range
- Sensitivity
- Readout rate
- Update rate
- Processing power
- Stray sun light
- Scattered transmit light
- Reliability
- SPE & SEP angles
- Acquisition time

Receiver (Optics)
- Aperture size
- Field-of- view
- Xmt-Rcv isolation
- Sensitivity
- Duplex operation
- Thermal effects
- Optics contamination

Platform
- Vibration environment (S/C jitter) - unknown
- Deadband cycle
- Earth exposure time

Space
- Radiation

Atmosphere
- Visibility
- Cloud cover
- Attenuation
- Elevation angle
- Sun angle
- Solar loading
- Turbulence
- Scattering

Earth
- Reflectance
- Albedo variations
- Crescent size
- Motion

Technology Developments at JPL

- Space-Based Transceiver Component and System Technology Development

- Ground-Based Receiver and Uplink Command/Beacon Technology Development

- Flight Terminal Development for Space-Station-to-Ground Communications

- Engineering Model Development for Deep-Space-to-Ground Communications

Current Technology Development Tasks

1. Research

Flight Transceiver Components & Algorithms

- Acquisition, Tracking and Pointing
  - both point- & extended-source
- Efficient solid-state Lasers
- Efficient modulation
- Fine-pointing mirrors
- High update-rate focal-plane-arrays
- Background sun-light avoidance

Ground Receiver/transmitter

- Atmospheric visibility monitoring
- Channel capacity, efficient modulation and coding
- Terrestrial test of lasercomm terminals
- Definition of large-aperture receivers
- Efficient detectors/amplifiers, receivers

2. Flight Programs:

ISSERT/OCD (near-earth)

- Up to 2.5 Gbps data-rate communications from LEO (International Space-Station) to Ground demonstration/facility

X2000 2nd Delivery (deep-space)

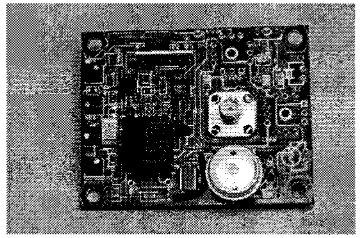
- Multi-function instrument:
  - 100 kbps from 2 AU from a 10-cm aperture on a micro-spacecraft
  - high-resolution science imaging
  - laser altimetry

Optical Communication Demonstrator (OCD)

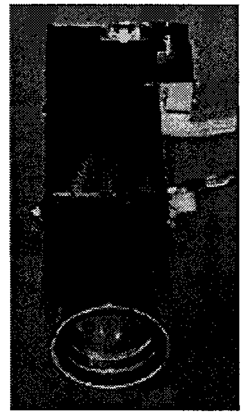
(Laboratory Model)

Fine-Pointing Mirror

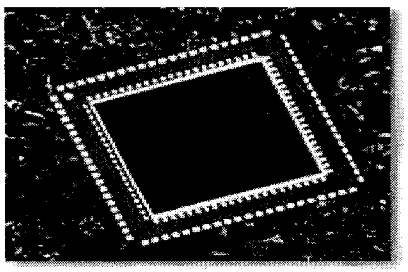
Data Receiver

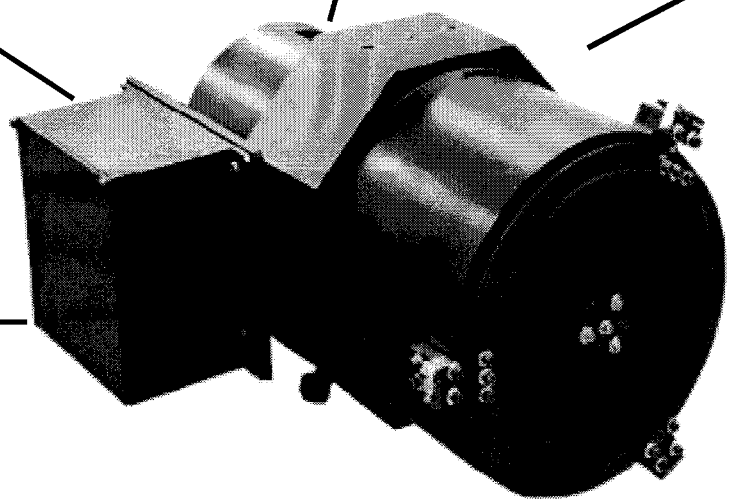


Laser Transmitter

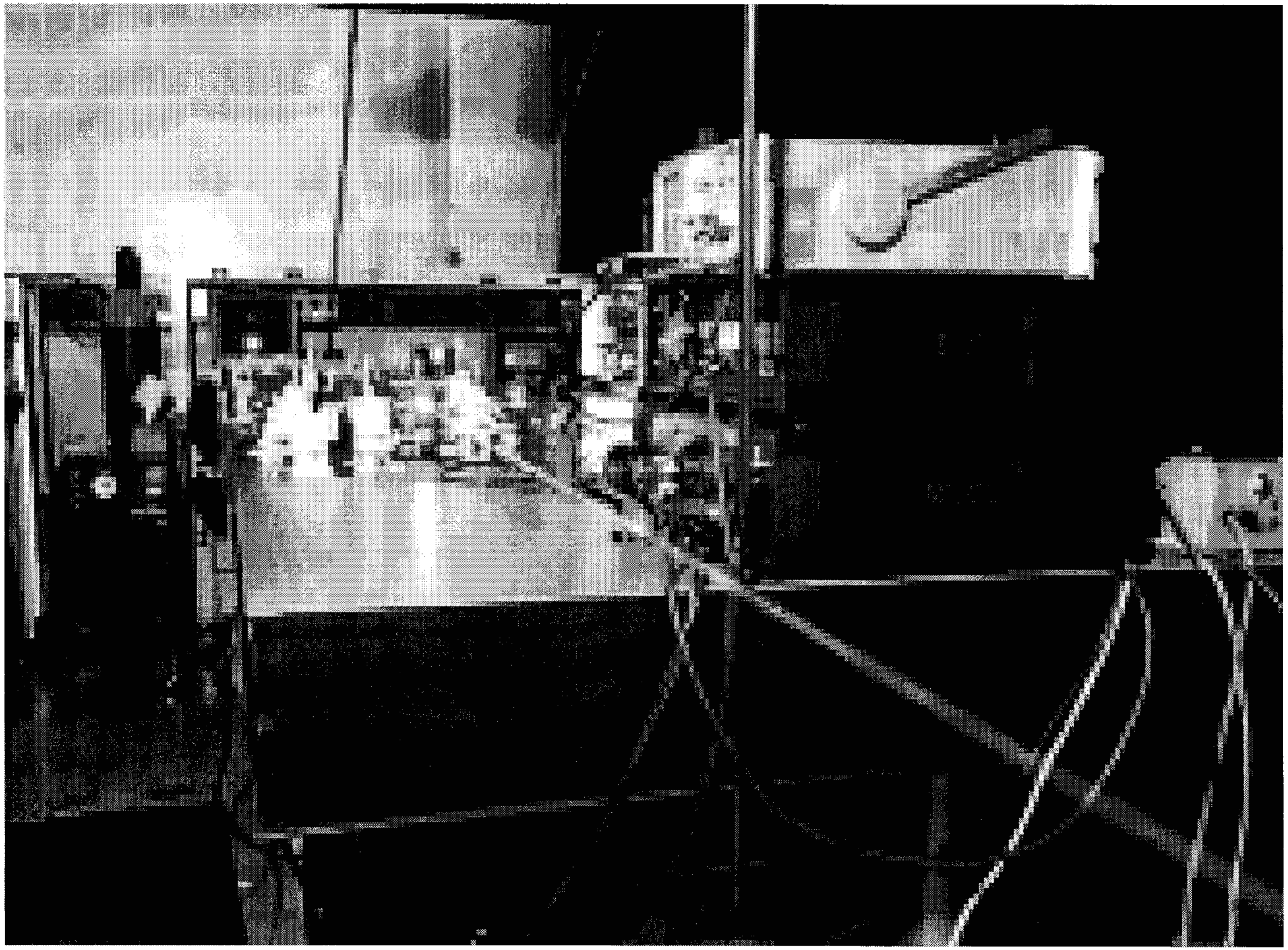


Focal Plane Array

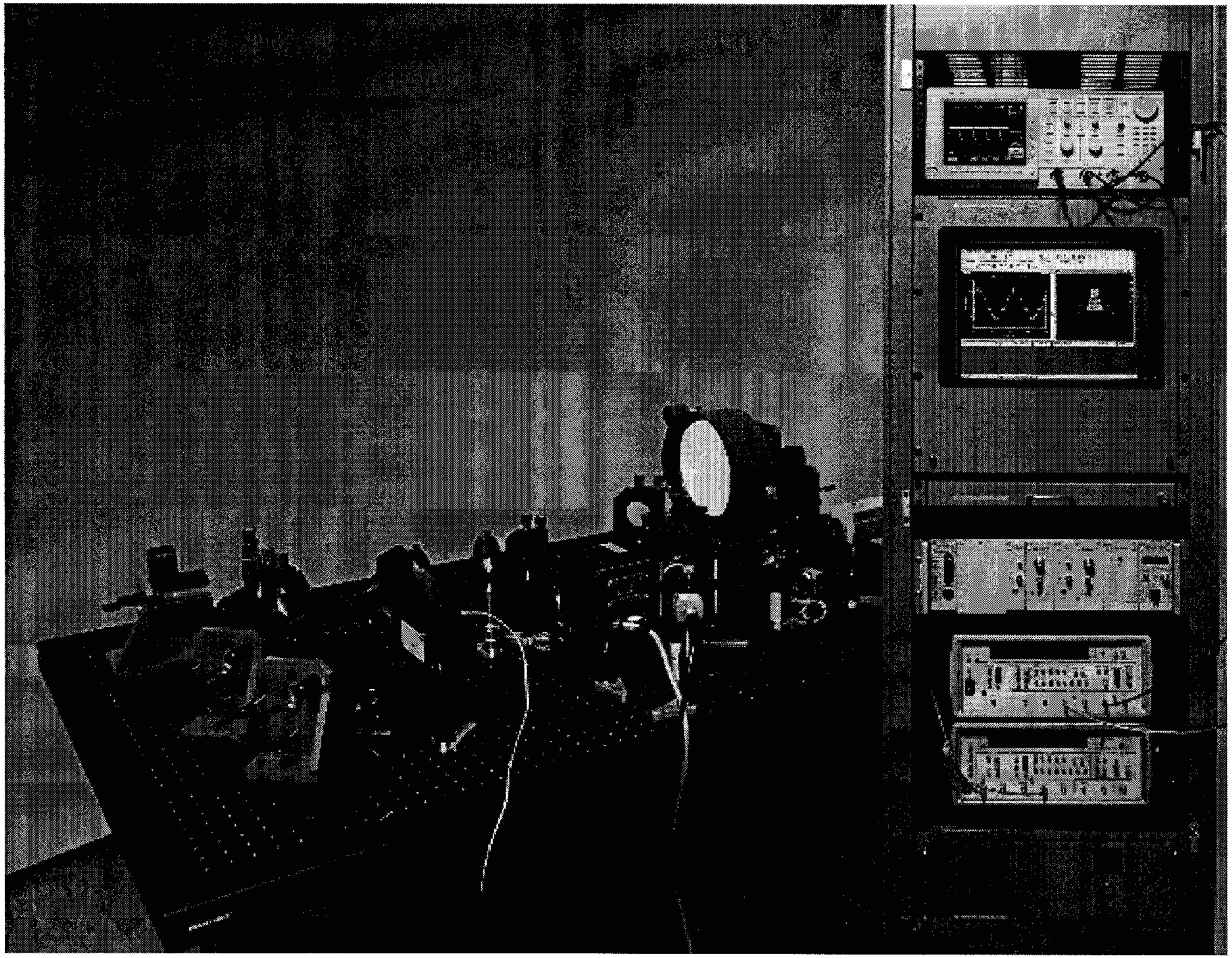




Efficient Laser Transmitters



LTES (Lasercomm Test & Evaluation Station)



PICTURE

Laser Transmitter / Receiver Testbed

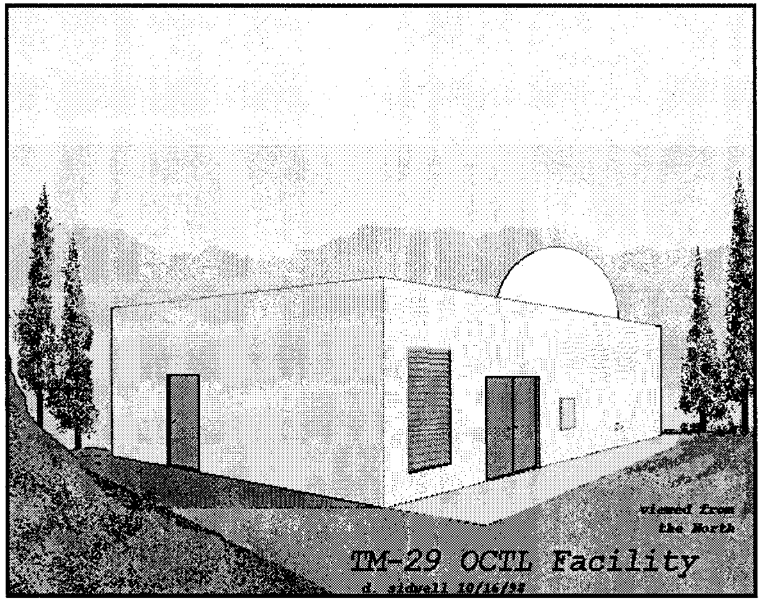
PICTURE

AVM
(Atmospheric Visibility Monitoring)

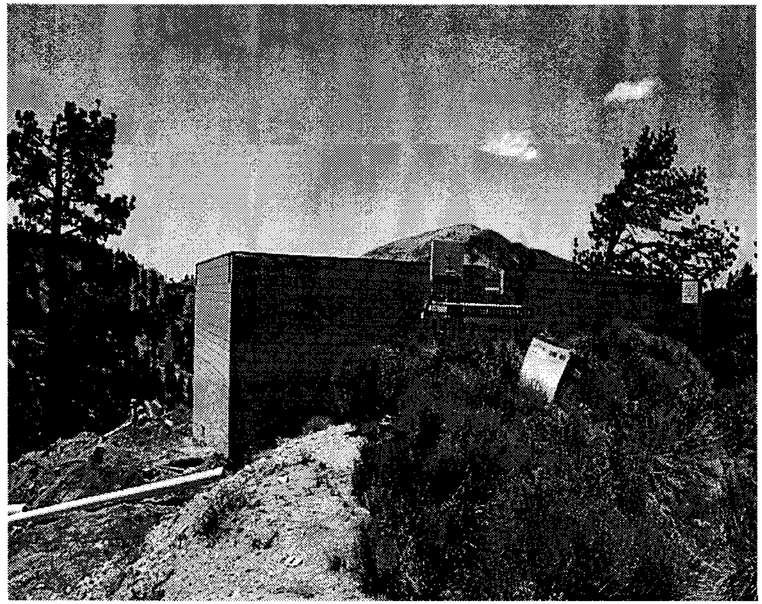
Set of three 10” autonomous telescopes to measure atmospheric visibility

OCTL
(Optical Communications Telescope Laboratory)

- A 1-m telescope facility to track LEO Spacecraft, dedicated to laser-communications
- Awarded 1 m telescope contract to Contraves Brashear Aug. 31, 1999
- Telescope will be delivered December 2000
- Initiated telescope building construction at JPL's Table Mountain Facility on May 1999

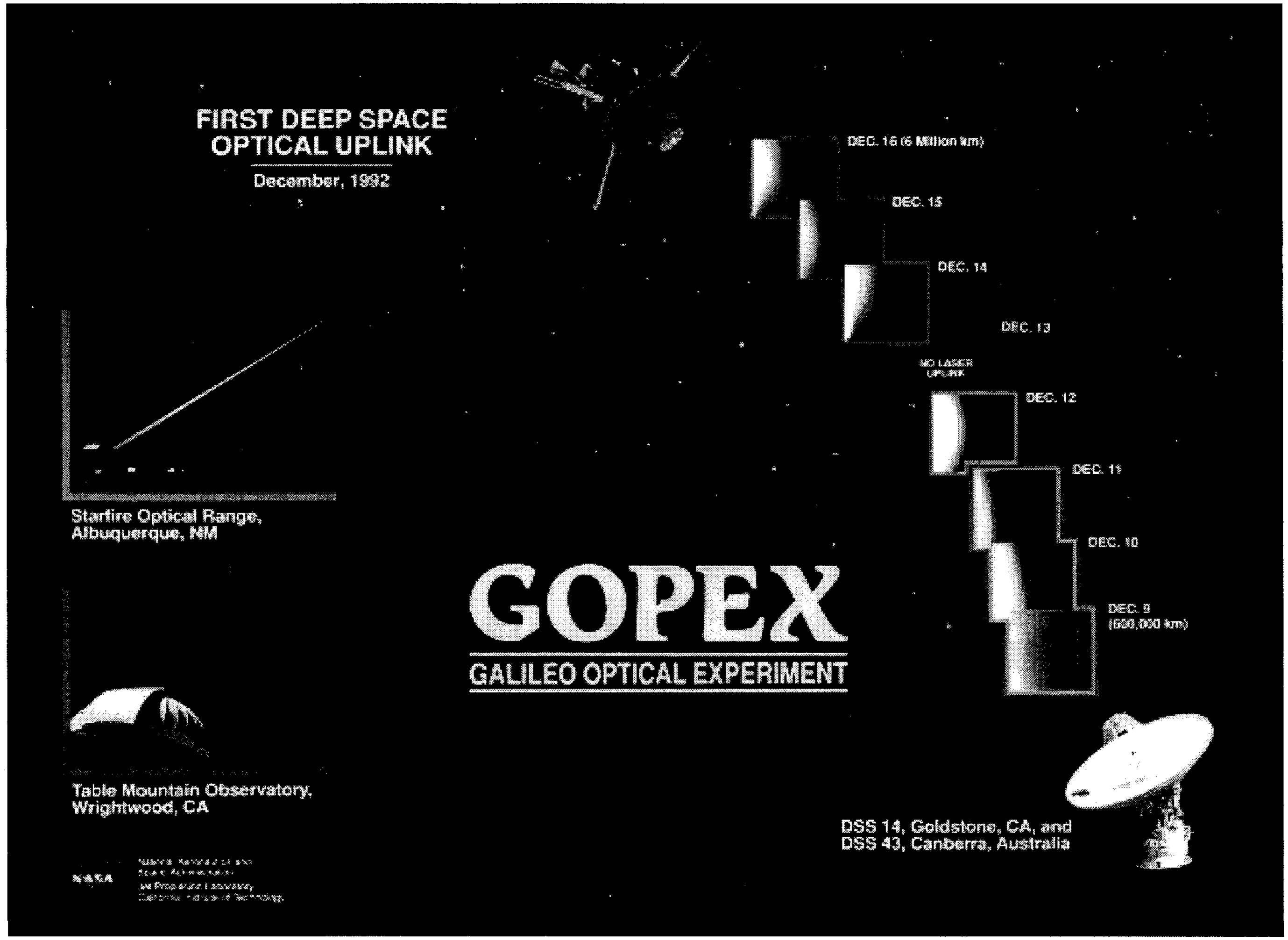


Artist's concept

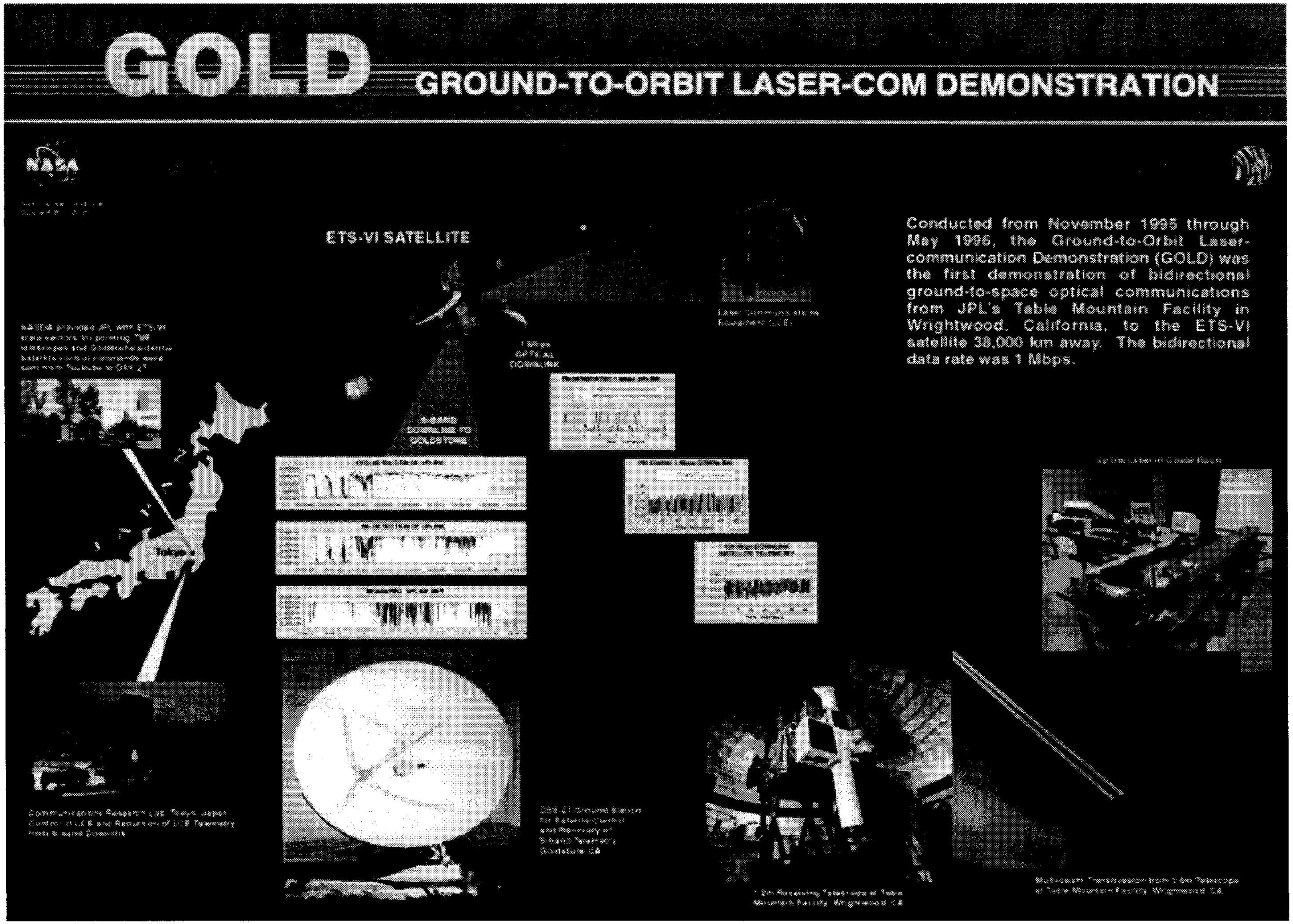


View of building from southeast direction

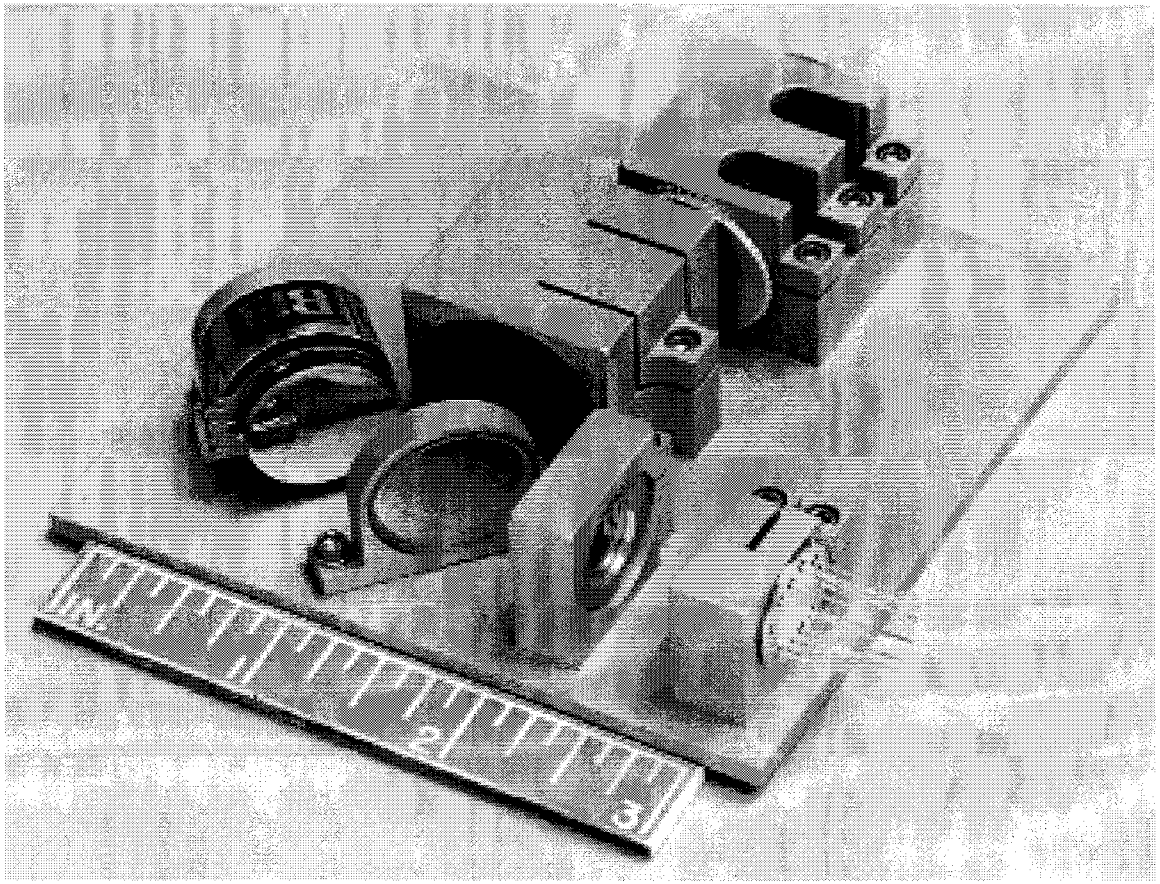
GOPEX (Galileo Optical Experiment)



GOLD
(Ground-to-Orbit Lasercom Demonstration)

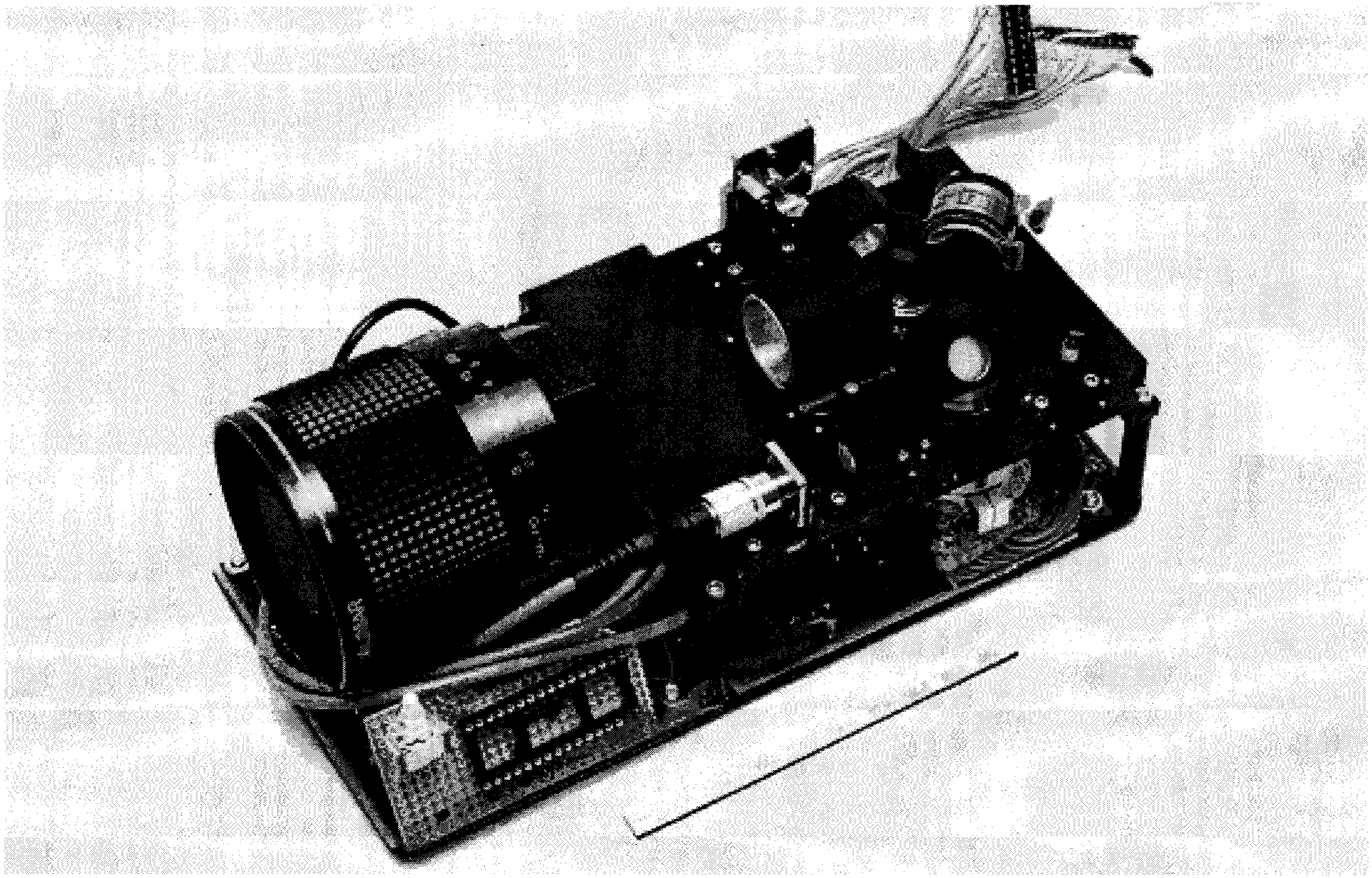


SCOPE
(Small Communications Optical Package Experiment)

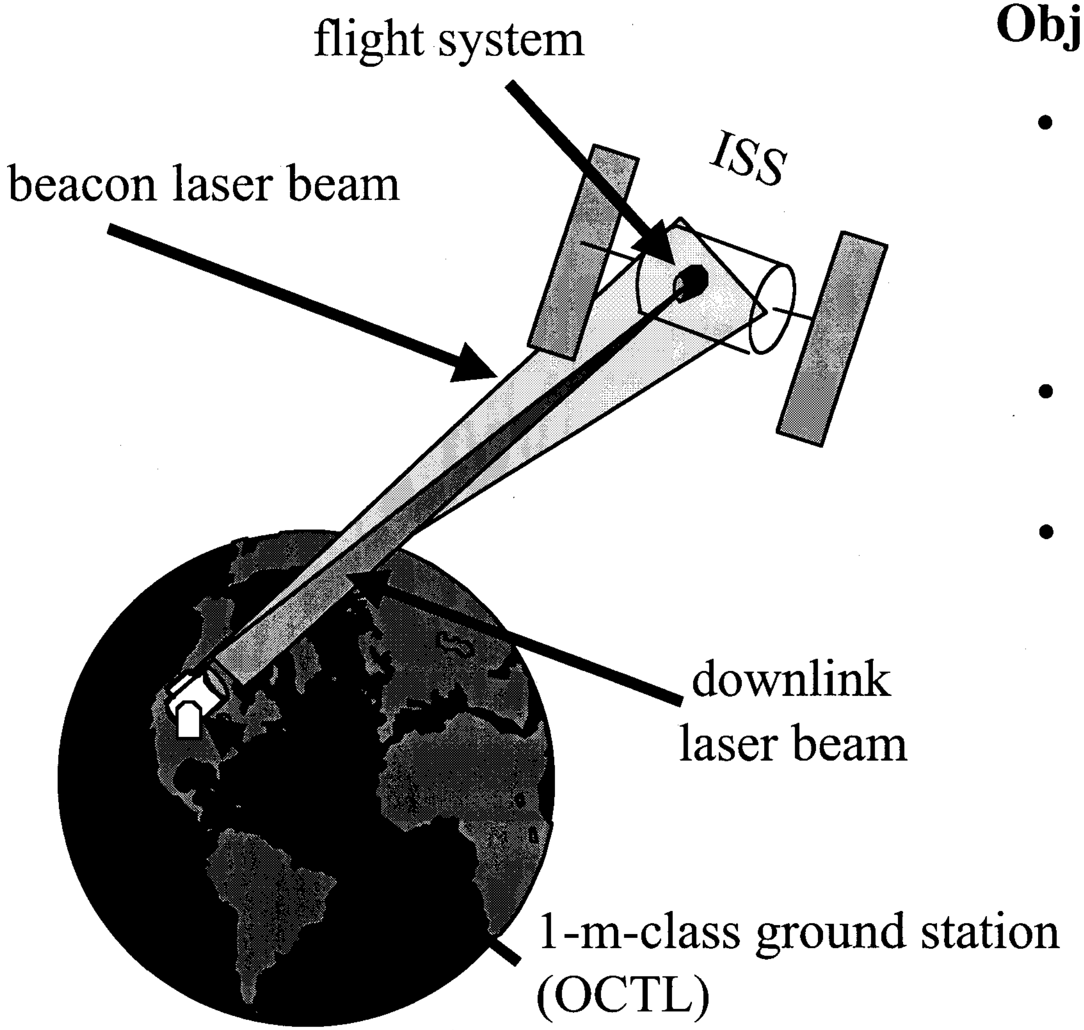


ACLAIM

(A Combined Lasercomm and Imager for Micro-spacecraft)



Flight Terminal for Space Station Demonstration/Facility



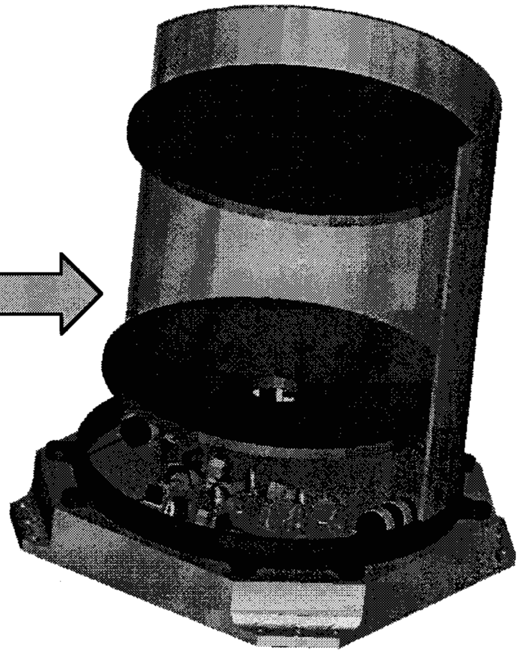
Objective

- Demonstrate high-rate (up to 2.5 Gbps) optical communication from the the International Space Station (ISS) to ground
- Provide a high-rate link facility capability
- Measure effect of atmosphere on beams

X2000 2nd Delivery Program
System Functions

High-Resolution Science Imaging

Laser-Communications

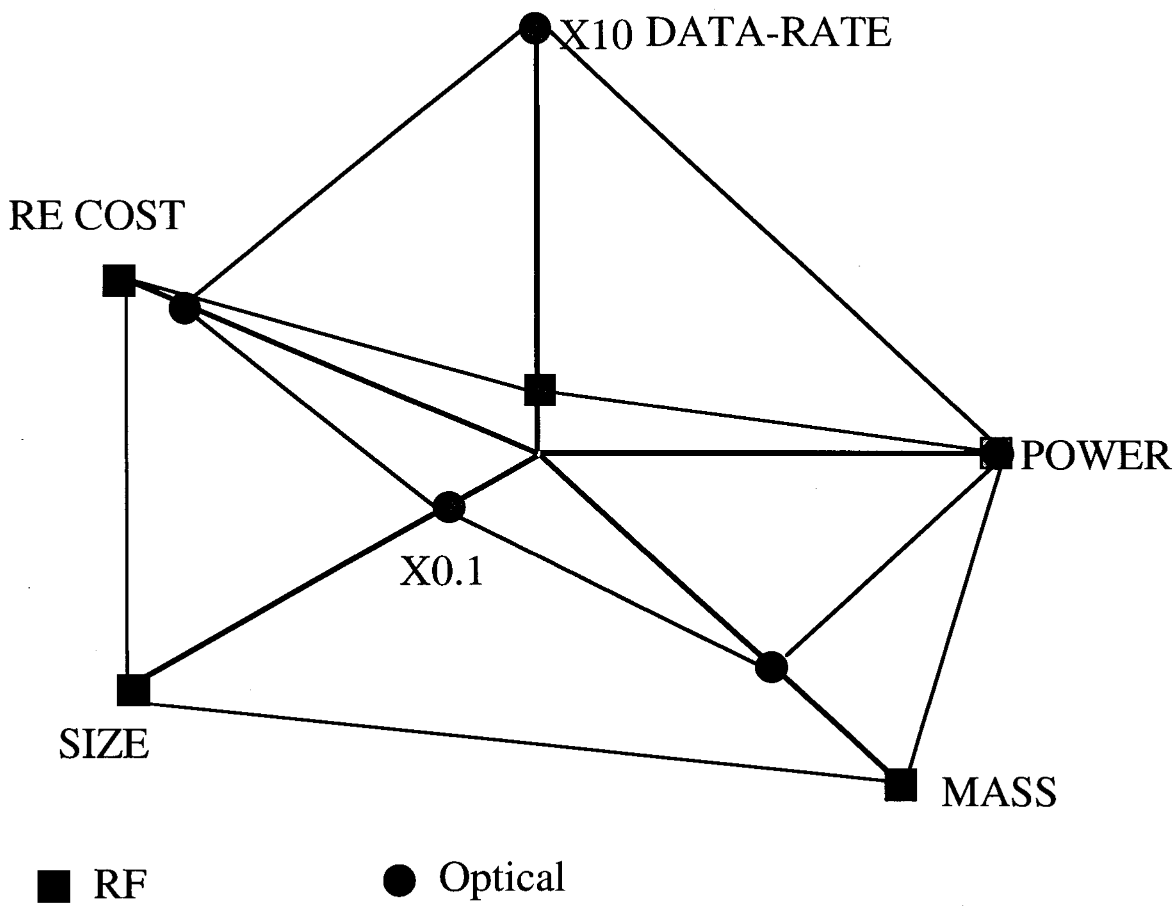


Hazard-Detection & Avoidance (for landing) &Laser-Altimetry

Major Remaining Technology Challenges

- A complete set of algorithms for Acquisition, Tracking &Pointing (ATP) for ranges of 0.01 AU to > 30 AU (using laser-beacon, Sun-illuminated Earth beacon and Sun beacon)
- Extended-source ATP when both Sun and Earth are within the field-of-view of the flight terminal telescope
- Sun-light avoidance and mitigation of background sun-light and scattered light effects
- Handling of spacecraft safety mode (emergency mode)
- Near-Earth acquisition and communication (first few days after launch)
- Development of inexpensive large aperture (> 10 m) ground receiver telescopes with sufficient surface quality for day-time reception

Promise of Technology Improvement Over RF Systems



Reference: ACBS Study, Published by SPIE 1996 & 1997
Performance is very much mission dependent

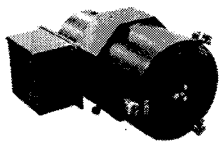
Deep Space Optical Communications Roadmap

Data-Rate Capability (Mbps)
Range = 1 AU
DC Power in = 40 W
Telescope diameter = 0.5 m

60

34 (HDTV)

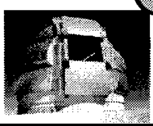
3



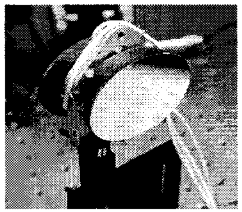
Optical Communication Demio.

- **10% Efficient Laser**
- **30% Q.E. APD Detector**

- **Space Station Demo**
- **X2000 Second Delivery Customers**



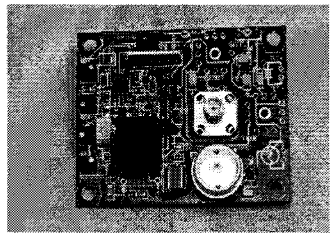
<---1-m R&D Station (OCTL)



Fine-Pointing Mirror

- **20% Efficient Laser**
- **40% Q.E. SLK APD**

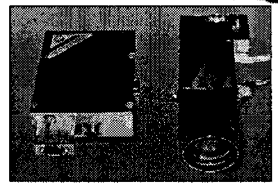
- **NMP, X2000**
- **Mars**
- **ARISE**
- **Comet Nucleus Sample return**



Photodiode / receiver

- **25% Efficient 10 W, 10 Mbps laser**
- **50% Q.E SLK APD detector**
- **0.2 nm, 90% transmission filter**

Neptune orbiter
- **Mars & Outer Planets**

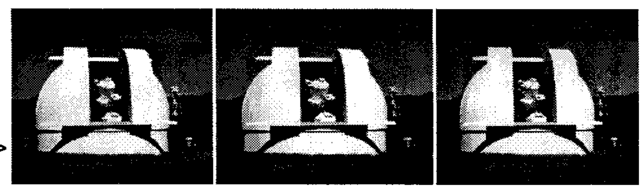


Laser Transmitter

- **30% Efficient laser**
- **65% Q.E APD**

•Interstellar Missions
•Mars & Outer Planets

10-m Ground Receivers --->



2003 **2007** **2010** **2025**

Conclusion

- Component component efficiency improvements are now underway
- Solutions to remaining technology challenges are being identified/ developed
- Several space-to-ground demonstrations are being worked on for near-Earth and deep-space
- Development of a network of large aperture ground receivers are planned

lead to establishment of a credible technology making reliable operational laser-communication a viable option